U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-268 961

Evaluation of the Technological Feasibility, and Cost of Selected Control Alternatives Necessary to Meet the Proposed Ohio SO2 Regulations for Industrial Boilers and Processes. Volume VIII. Union Carbide Carbon Products Division, Fostoria Plant

GCA Corp, Bedford, Mass. GCA Technology Div.

Prepared for

Environmental Protection Agency, Chicago, Ill. Air and Hazardous Materials Div.

Aug 76

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-905/2-76-005-h		

4. TITLE AND SUBTITLE
Evaluation of the Technological Feasibility and Cost of Selected Control Alternatives Necessary to Meet the Proposed Ohio SO_2 Regulations for Industrial Boilers and Processes. Volume VIII

5. REPORT DATE
August 1976

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
GCA Corporation
GCA/Technology Division
Bedford, Massachusetts

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-01-3155
Task Order No. 4

12. SPONSORING AGENCY NAME AND ADDRESS
Air Programs Branch, A&HMD
Environmental Protection Agency, Region V
Chicago, Illinois 60604

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
One of 9 documents supporting sulfur dioxide control strategy for the State of Ohio Technical Support Document Vol. I and II EPA 905/2-76-002

16. ABSTRACT
This report presents an evaluation by the GCA Corporation, GCA/Technology Division, of technological feasibility and cost of complying with the proposed Ohio sulfur dioxide regulation (40 FR 52410, November 10, 1975) at Union Carbide's Fostoria Activated Carbon Plant. The final USEPA Sulfur Dioxide Control Strategy for the State of Ohio Technical Support Documents, Vol. I and II, (EPA 905/2-76-002) may be obtained from NTIS.

Union Carbide employs a unique activation process using sulfur that would be affected by the proposed regulation. A sulfur dioxide emission reduction of 96.8 percent would be required. After collecting necessary process and site specific data by means of a plant visit, the technical feasibility and cost of lime scrubbing to achieve the required sulfur dioxide reduction were determined.

17. KEY WORDS AND DOCUMENT ANALYSIS

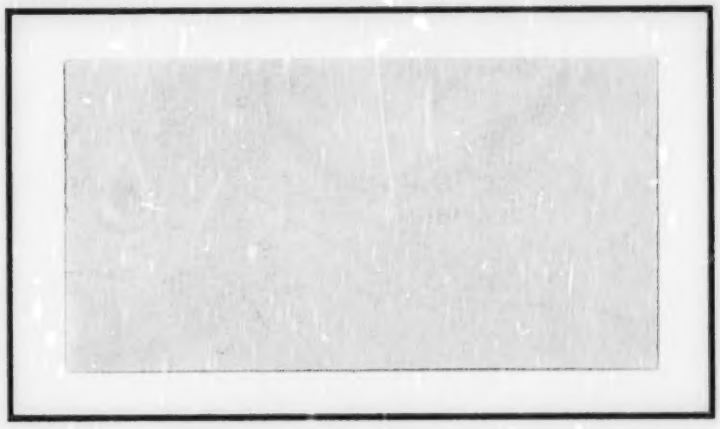
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Activated Carbon Activation Sulfur Sulfur Dioxide	Carbon Products Control Strategy Lime Scrubbing Ohio Union Carbide	13B 13H

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)*	22. PRICE

31
A03 - A01

EPA Form 2220-1 (9-73)

PB 268 961



GCA/TECHNOLOGY DIVISION

EPA-905/2-76-005-h

GCA-TR-76-14-G(8)

EVALUATION OF THE TECHNOLOGICAL FEASIBILITY, AND COST OF SELECTED CONTROL ALTERNATIVES NECESSARY TO MEET THE PROPOSED OHIO SO_2 REGULATIONS FOR INDUSTRIAL BOILERS AND PROCESSES

FINAL REPORT

Contract No. 68-01-3155
Task Order No. 4

August 1976

Volume VIII

UNION CARBIDE

CARBON PRODUCTS DIVISION

FOSTORIA PLANT

by

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This Final Report was furnished to the Environmental Protection Agency by the GCA Corporation, GCA/Technology Division, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-01-3155, Task Order No. 4. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency or of the cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

ABSTRACT

The results of an evaluation of the technical feasibility, and cost, at Union Carbide's Fostoria activated carbon plant, of complying with the proposed Ohio SO_2 emission regulation are presented in this report. Union Carbide employs a unique activation process using sulfur that would be affected by the proposed process regulation. An SO_2 emission reduction of 96.8 percent would be required. The technical feasibility, and cost, of lime scrubbing to achieve the required SO_2 emission reduction were determined.

CONTENTS

		Page
Abstract		iii
List of Figures		v
List of Tables		vi
Acknowledgments		vii
Sections		
I	Summary and Conclusions	1
II	Process and Site Description	2
III	SO_2 Control Methods for Union Carbide's Fostoria, Ohio Activated Carbon Plant	8
IV	Cost of SO_2 Control	16
V	References	21

FIGURES

No.		Page
1	Site Layout Union Carbide Corporation, Carbon Products Division, Fostoria Plant	3
2	Union Carbide Activated Carbon Process	5
3	R-C Lime (Bahco) Scrubber System	12

TABLES

No.		Page
1	Summary of Process and Emission Data for Union Carbide Activated Carbon Process	6
2	Design Conditions for Flue Gas Desulfurization to Comply With the Proposed Regulations	7
3	Bahco SO_2 Removal System Installations	11
4	Research-Cottrell Lime (Bahco) Scrubbing System	13
5	Utility, Material, and Labor Requirements for Flue Gas Desulfurization Based on Maximum Rated Capacity of the Calcining and Activating Furnaces	17
6	Utility, Material, and Labor Costs for Flue Gas Desulfurization at Union Carbide's Fostoria Activated Carbon Facility, $\$10^3$/yr	19
7	Capital and Annual SO_2 Control Costs at Union Carbide's Fostoria Activated Carbon Facility, $\$10^3$, June 1976	20

ACKNOWLEDGMENTS

The assistance of Mr. Wayne E. Pearson, Project Officer, and Mr. Thomas Blaszak, U.S. Environmental Protection Agency, Air Policy Branch, Region V, Chicago, Illinois is gratefully acknowledged.

SECTION I

SUMMARY AND CONCLUSIONS

Union Carbide Carbon Products Division uses sulfur as a raw material in a unique process for the manufacture of activated carbon. SO_2 emissions from the Herreshoff calciner and Herreshoff activator are about 5400 tons per year. GCA visited the facility to evaluate the technical feasibility, and cost, of controlling SO_2 emissions to meet the proposed process regulation for control of SO_2 in the State of Ohio. This regulation would require a 98 percent reduction of SO_2 emissions from the calciner and a 92 percent reduction from the activator.

Lime scrubbing with water sprays for precooling could be used to meet the proposed regulation. The two flue gas streams would be combined to form a 26,000 scfm stream containing 6500 ppm SO_2. A 96.8 percent SO_2 collection efficiency would then be required to meet the proposed regulation. Total capital requirement for the control system would be $2.3 million. Annual control cost including cost of capital, depreciation, operating cost and federal income tax would be $916,000 year or $0.176 per pound of sulfur removed. These costs are equivalent to $0.072 per pound of activated carbon produced which compares to an activated carbon selling price of $0.43 to $1.65.

SECTION II

PROCESS AND SITE DESCRIPTION

Union Carbide, Carbon Products Division, manufactures activated carbon, projection and welding carbons, battery electrodes and carbon brushes at their Fostoria, Ohio plant. A unique process employing sulfur is used to produce activated carbon. SO_2 emissions from incineration of the off gas produced in manufacturing activated carbon amount to approximately 5400 tons/year. The proposed process regulation would require that these emissions be reduced by over 95 percent. GCA visited the Fostoria plant on Wednesday, April 28, 1976, to collect, process and site specific data on the activated carbon operation in order to determine the technical feasibility, and cost, of complying with the proposed regulation. Mr. Steve Dorr, chief plant engineer and Mr. William Glasgow, project engineer, represented Union Carbide. Several other Union Carbide employees also attended the meeting.

The site layout in the vicinity of the activated carbon facility is presented in Figure 1. Space for flue gas desulfurization equipment is clearly available near the small and large Herreshoff furnaces. However, some of the space is reserved for plant expansion and land for ponding of scrubber sludge is not available. Sludge would have to be hauled to an offsite disposal site. No wastewater treatment facilities exist at the plant and waste water is presently discharged to city sewers.

Union Carbide's Fostoria, Ohio plant started operating around 1900. The present activated carbon process has been in use since 1962 but other activating processes were used previously. Present plans are to continue

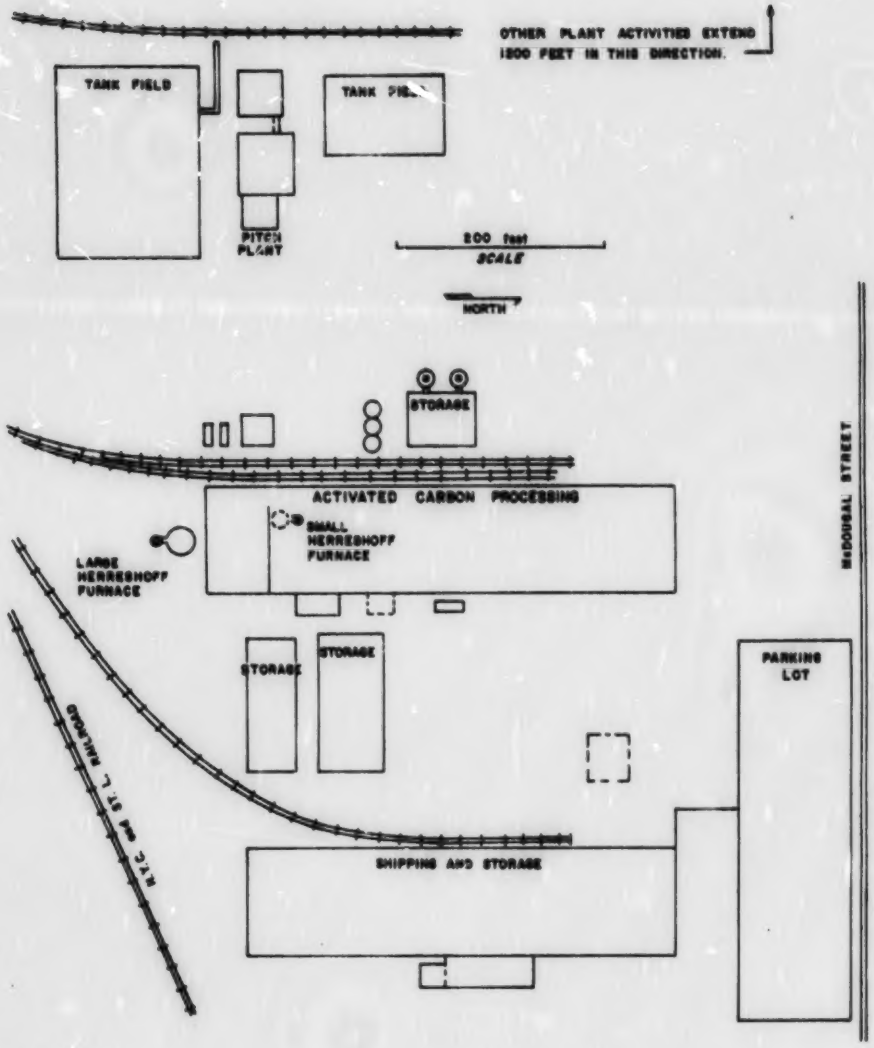

Figure 1. Site layout Union Carbide Corporation, Carbon Products Division, Fostoria Plant

manufacturing activated carbon through the foreseeable future. The plant is shut down once a year for 1 month and all required maintenance is performed. There are basically two types of activated carbon. One is a powder used in purification of liquids and the other is a granular or pelletized material used for adsorption of gases or vapors. The Fostoria plant manufactures a high density activated carbon of the latter type specially suited for solvent recovery and air purification. Several grades of activated carbon are produced ranging from the lowest grade used in ductless hoods and selling for $0.43/lb to the highest grade used in solvent recovery and selling for $1.63/lb. The normal production rate is 900 lb/hr of activated carbon.

The process used by Union Carbide consists primarily of three operations pelletizing, calcining and activating. Initially coal or coke and the binder are milled and then mixed with elemental sulfur and an extrusion lubricant. This mix is pelletized and then continuously charged to the small Herreshoff calciner as shown in Figure 2. The feed to the calciner contains 10 to 20 percent sulfur. Natural gas is used to fire the calciner driving off 80 percent of the volatiles and 50 to 80 percent of the sulfur. Off gas is then incinerated and exhausted through an 88 foot stack. Normal SO_2 emission rate is 1225 lb/hr.

After screening the calcined pellets are transferred to the large Herreshoff activator which is fired with distillate oil and natural gas. Porosity is imparted to the pellets by activating them in a reducing atmosphere. During activation most of the remaining sulfur is removed and exits through a 120 foot stack. The normal SO_2 emission rate from the large Herreshoff activator is 202 lb/hr. Union Carbide tests indicate that the flue gas contains 8.8 percent oxygen, 0 percent carbon monoxide, and leaves the stack at 1600°F.

The operation of both the calciner and activator would be affected by the proposed process regulation. This regulation, §52.1881(b)(3) states the following:

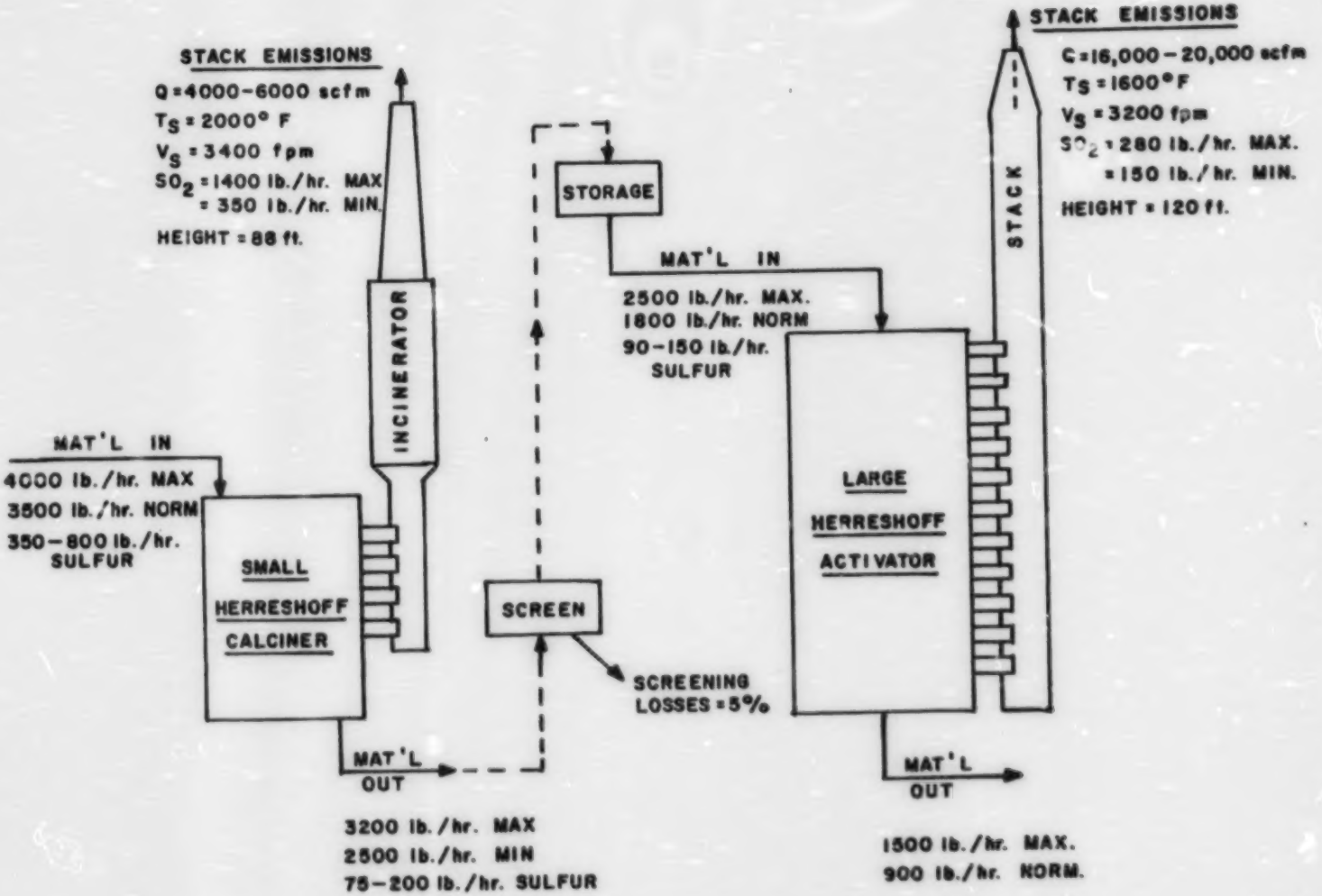

Figure 2. Union Carbide activated carbon process[1]

"Except as provided in paragraphs (6), (7), (9), (10), (11), (12), and (13) of this section, no owner or operator of any process equipment shall cause or permit the emission into the atmosphere of any process gas stream containing sulfur dioxide in excess of the amount prescribed by the following equation:

$$E = 19.5_{p}^{0.67}$$

where E is the allowable emission rate in lbs SO_2/hour and P is the tons of process weight per hour."[2]

The regulation applies to each furnace as separate processes. Therefore, at the maximum operating rate of 2 ton/hr, SO_2 emissions from the calciner are limited to 31 lb/hr. A reduction of 97.8 percent from 1400 lb/hr would be required for the calciner. The activator would be limited to 22.6 lb SO_2/hr at its maximum operating rate of 1.25 ton/hr. Emissions from the activator would need to be reduced 91.8 percent from 280 lb SO_2/hr at the maximum operating rate. Process and emission data for the Union Carbide activated carbon process are summarized in Table 1.

Table 1. SUMMARY OF PROCESS AND EMISSION DATA FOR UNION CARBIDE ACTIVATED CARBON PROCESS

	Normal operation		Maximum operation	
	Calciner	Activator	Calciner	Activator
Process weight, ton/hr	1.75	0.9	2	1.25
Allowable SO_2 emissions rate, lb/hr	28.4	18.1	31.0	22.6
Actual SO_2 emission rate, lb/hr	1,225	202	1,400	280
SO_2 emission reduction required, percent	97.7	91.0	97.8	91.9
lb/hr	1,196.6	183.9	1,369	257.4
Flue gas flow rate, scfm[a]	5,250	16,000	6,000	20,000
Flue gas temperature, °F	2,000	1,600	2,000	1,600
SO_2 concentration, ppm	23,500	1,270	23,500	1,410
Allowable SO_2 concentration, ppm	540	114	517	114

[a] 77°F, 1 atm

Although separate treatment of the two flue gases is possible, GCA elected to analyze a system to treat the combined flows. This method was selected because it appears to be the most technically feasible method. Design conditions for flue gas desulfurization are presented in Table 2. The system would be designed to operate at a 96.8 percent SO_2 collection efficiency, at a flow of 26,000 scfm and at an inlet SO_2 concentration of 6510 ppm.

Table 2. DESIGN CONDITIONS FOR FLUE GAS DESULFURIZATION TO COMPLY WITH THE PROPOSED REGULATIONS[a]

	Normal operation	Maximum operation
SO_2 emission rate before control, lb/hr	1,427	1,680
Required SO_2 emission reduction, lb/hr	1,381	1,626
SO_2 collection efficiency required	96.8	96.8
Inlet SO_2 concentration, ppm	6,760	6,510
Outlet SO_2 concentration, ppm	216	208
Flue gas temperature before precooler, ^oF	1,700	1,700
Flue gas flow rate, scfm	21,250	26,000
Moisture content, percent	5-20	5-20

[a]GCA's approach would be to combine both stack gas flows and treat them together. Data in this table are based on Table 1.

SECTION III

SO_2 CONTROL METHODS FOR UNION CARBIDE'S FOSTORIA, OHIO ACTIVATED CARBON PLANT

PROCESS MODIFICATIONS

The process used by Union Carbide to produce activated carbon is apparently unique and no similar facilities are known to exist.[1] Union Carbide is continuing investigations to limit the sulfur content of the process feed and still produce a product of equivalent quality. These efforts are directed towards the outdated regulation of 2000 ppm SO_2 proposed by Ohio in 1972. The activator would have compiled with the 2000 ppm limit but emissions from the calciner would have required a reduction of over 90 percent.

Union Carbide has continued their development work on the new process and the first production run was made in June 1976. As might be expected with a new process the results were not completely satisfactory. Further development work and testing of the materials produced in the first run may be required. In any case it appears that this process would not be applicable if the presently proposed regulation is approved. As previously discussed the newly proposed regulation would limit SO_2 emissions (lb/hr) to an equivalent 517 ppm from the calciner and 114 ppm from the actifier. These limits are below the capability of the new process. Flue gas desulfurization would be required and the new process would not be used even though it would simplify the flue gas cleaning.

FLUE GAS DESULFURIZATION

During 1973 and 1974 Union Carbide contacted 34 companies to determine the technical feasibility and cost of meeting the previously proposed 2000 ppm SO_2 emission limit for the calciner. Emphasis appears to have been on small sulfur recovery systems to clean the 4000 to 6000 scfm of flue gas leaving the calciner. Although the system size would be extremely small, the available sulfur would be reasonably high (about 8 tons/day) and Union Carbide could, of course, use all recovered sulfur on site. However, under the currently proposed regulation 16,000 to 20,000 scfm from the activator would also have to be cleaned and desulfurization of both sources would have to be more efficient. This second stack gas stream contains a much lower SO_2 concentration.

A lime scrubbing system was selected by GCA as being the most appropriate control measure for several reasons. First, a single lime system could be used to control both streams instead of using a small sulfur recovery system for the calciner and a flue gas scrubber for the activator. Second, the technology of scrubbing has been demonstrated commercially in the past several years. Lime scrubbers with proper design can achieve the 97 to 98 percent SO_2 efficiencies required. Finally, the small volume of gas that must be cleaned would appear to favor wet scrubbing. Union carbide mentioned that waste heat recovery would be required. With present energy costs waste heat recovery would at first appear to be economically desirable but again the small size of the system and the flue gas composition could alter the attractiveness. GCA proposes to use water spray cooling in this evaluation. In addition to lime scrubbing, other systems are available and the double alkali system manufactured by FMC* for small boilers and industrial processes should be applicable.

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*FMC Corporation, Environmental Equipment Division, Westport, Connecticut.

Lime scrubbing systems are manufactured by numerous engineering construction firms and have been in use on utility boilers for several years. Although lime scrubbing is very similar to limestone scrubbing, there are several potential advantages of using lime, particularly for smaller systems. Raw material transport costs are lower, maintenance and scaling may be reduced, raw material utilization is more effective, and solid waste quantities are slightly lower. Twenty lime scrubbing systems designed to clean 16,000,000 scfm of flue gas are operating, under construction, or committed to construction on large boilers in the U.S.[3]

Although the Bahco system currently being marketed by Research-Cottrell uses lime as the adsorbent, the same scrubber has been used with other adsorbents. Table 3 illustrates the commercial application of Bahco scrubbers to small boilers and process sources. This table indicates that the Bahco system is a technically feasible SO_2 scrubbing system but it is recognized that the economic feasibility varies with the source type and may be different in the U.S. The cost of SO_2 control is discussed in Section IV.

The Research-Cottrell* Bahco-lime scrubbing system (see Figure 3) consists of a two-stage venturi. The first venturi presaturates the gas, removes some SO_2 and may be designed to remove particulates. At the bottom of the column, flue gas is directed down against the surface of a milk lime slurry. The high velocity gas-liquid contact produces a vigorous cascade of droplets that carry up into the first scrubber stage for turbulent mixing with the flue gas. Above the first venturi, droplets are separated in an inertial collector while the gas continues up to a second stage where the gas-liquid contact process is repeated. A mist eliminator above the second stage frees the gas of droplets prior to exiting out the stack. Separated liquids from both stages of the venturi return to the lower

*Research-Cottrell, P. O. Box 750, Bound Brook, N.J.

Table 3. BAHCO SO_2 REMOVAL SYSTEM INSTALLATIONS[4]

Company	Location	Number of units	Unit capacity scfm @ 77°F	Service	Scrubbing reagent	Inlet SO_2 concentration	SO_2 removal efficiency %	On-line
Sodersjukhuset	Stockholm, Sweden	3	19,300	Oil-fired boiler	$Ca(OH)_2$	800 - 1500 ppm	97 - 99	Nov. 1969, April. 1970
Daishowa Seishi Company	Suzukawa, Japan	1	16,000	Oil-fired boiler	NaOH	900 - 1200 ppm	97 - 99	Jul. 1970
Daishowa Seishi Company	Yoshinaga, Japan	5	48,200	Oil-fired boiler	NaOH	900 - 1000 ppm	97.5	Aug. 3, 1970/ Jul. 2, 1972
Osaka City	Osaka, Japan	1	11,000	Secondary sludge incinerator	NaOH	70 - 80 ppm	50[a]	Mar. 1971
Hiroshima City	Hiroshima, Japan	1	11,000	Secondary sludge incinerator	NaOH			Dec. 1970
Yahagi Iron Works	Nagoya, Japan	1	53,000	Sintering Plant	$Ca(OH)_2$ Waste Carbide Sludge	2500 - 4000 ppm	90 - 95	Dec. 1970
Taio Paper Company	Iyomishima, Japan	1	90,600	Oil-fired boiler	NaOH	1000 - 1500 ppm	98	Jan. 1971
		1	72,500	Oil-fired boiler	NaOH	1000 - 1500 ppm	98	Jan. 1971
Central Glass Company	Sakai, Japan	1	34,200	Glass furnace	NaOH	1200 ppm (25% SO_3)	98	Mar. 1971
Stora Kopparberg	Gryckbo, Sweden	1	19,300	Black liquor boiler	CaO and $CaCO_3$ dust	4000 - 6000 ppm	70[a]	Sept. 1972
Kanegafuchi Chemical	Takasago City, Japan	2	173,000	Oil-fired boiler	NaOH	1400 - 1530 ppm	95 - 98	Apr. 1973
Kino Ura Utility	Japan	1	81,900	Oil-fired boiler	NaOH	1500 ppm		Sept. 1974
Rickenbacker Air Force Base	Colmbus, Ohio	1	54.500	Coal-fired boiler	CaO	4000 ppm	90[a]	Feb. 1976

[a]Sufficient to meet local code.

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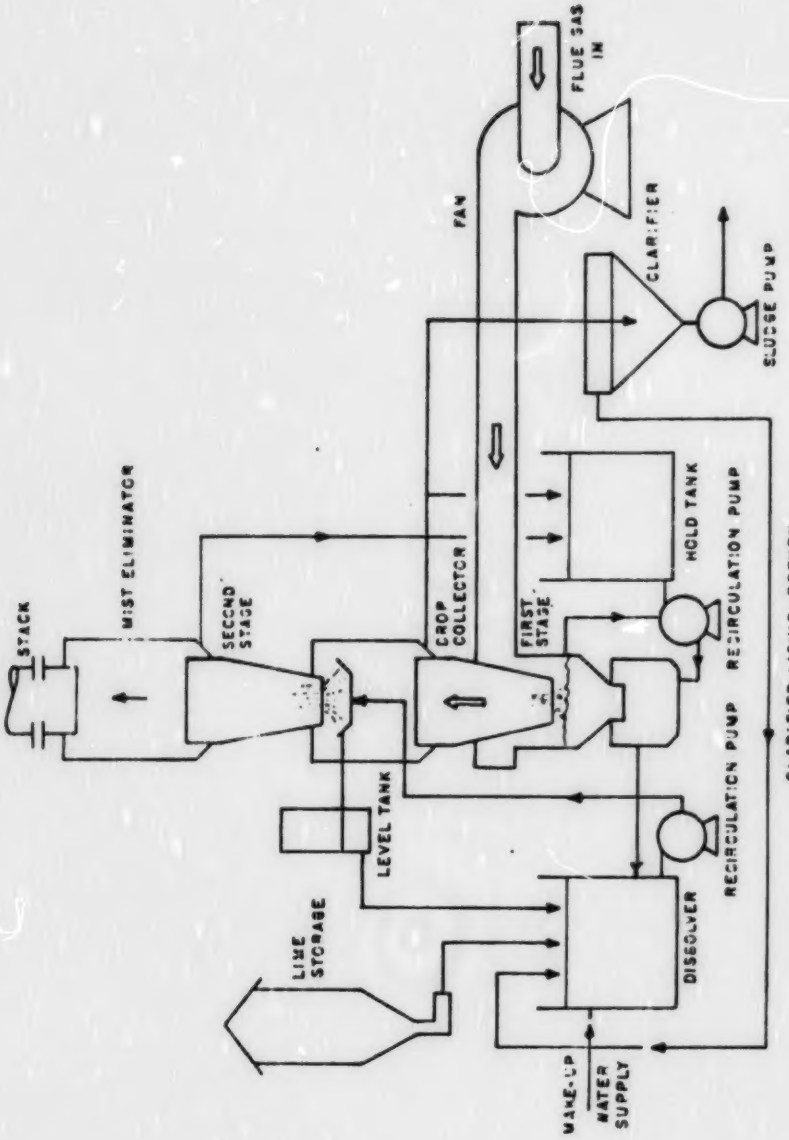

Figure 3. R-C lime (Bahco) scrubber system[5]

impingement zone. A fraction of this return flow is continuously removed for disposal, usually to a thickener. Clarified liquid is returned to the lime-dissolving tank to minimize makeup requirements.[5] Operating and design characteristics of the Bahco system are summarized in Table 4.

Table 4. RESEARCH-COTTRELL LIME (BAHCO) SCRUBBING SYSTEM[6]

Smallest system capacity commercially available (scfm)	20,000
Overall pressure drop through system (in H_2O)	16 - 26
Turndown ratio of system[a]	1.5 - 1
SO_2 removal efficiency, percent	90 - 99
Raw materials	Lime
By-products	None
Wastes[b] lb waste/lb SO_2 removed	6.1 lb cake containing 35 percent solids ($CaSO_3$ and $CaSO_4$) and 65 percent water
Maintenance	Scaling and solids deposition appear to be less severe than for limestone based scrubbing systems. Corrosion can be minimized by properly designing the system.
Development status (see Table 3)	Operational systems in the United States 55,000 scfm 3.6% S coal

[a]Any turndown ratio may be accommodated by the addition of makeup air.

[b]Does not include the particulates that would be removed.

Sludge Disposal

Nonregenerative scrubbing systems for SO_2 control produce sludges that must be utilized or disposed. Sludges produced by lime and limestone SO_2 scrubbing systems contain primarily calcium sulfite, calcium sulfate, calcium carbonate and fly ash. At Union Carbide the fly ash and trace metal components will be insignificant. Water content is typically 50 to 80 percent. An environmentally acceptable method for sludge disposal

or utilization must be considered in the evaluation of the technical feasibility and cost of scrubbing. Numerous options have been proposed for sludge utilization[7] but significant application of these techniques, especially to small systems, appears to be unlikely. A recent EPA sponsored study concluded that ponding and landfill are the only near term alternatives for sludge disposal.[8]

In order to assess this problem it is useful to compare the properties of scrubber sludge to coal fly ash. First, sludge tends to be more difficult to dewater either by settling or filtration and rewaters more easily. The platelet-like crystal structure of calcium sulfite hemihydrate ($CaSO_3$-1/2 H_2O) is believed to be primarily responsible for the high moisture retention.[9] Depending on the sludge composition including the amount of fly ash it will settle to 30 to 65 percent solids compared to fly ash which settled to 80 percent solids. Dewatering problems lead to increased processing costs, larger ponding areas and poorer landfill characteristics. Untreated sludge liquors have a lower pH than fly ash liquors thus causing greater trace metal solubility.[10] However, at Union Carbide most of the trace metals probably remain in the activated carbon decreasing the potential trace metal solubility problem.

Ponding is currently the most commonly used lime/limestone sludge disposal method. Surface water pollution from direct wastewater discharge is a potential problem. Eight full scale systems representing over 3 million scfm of flue gas cleaning capacity have eliminated this problem by recirculating the scrubber liquor; i.e., closed loop operation.[11] Other installations recirculate as much of the liquor as technically feasible. Pollution of ground and surface waters from leachate formation is also a potential problem. Ponds may be lined with clay or synthetic materials like asphalt, PVC, Hypalon, etc.[12] The necessity for lining and/or stabilization depends on local regulations, sludge characteristics and local geology and hydrology. Currently, only Commonwealth Edison, Will County No. 1 is using a lined (clay) pond[3] but future requirements will probably be more stringent.

Costs for sludge disposal by ponding can vary very widely, depending on land cost; the type of liner used, if any; location of the pond in relation to scrubbers; and the settling characteristics of the sludge. The need for a pond liner and the type used and therefore the disposal cost will depend on local geology, hydrology and environmental regulations. It has been suggested that the small size of some industrial boilers and processes may reduce the sludge disposal problem as local environmental impacts will be reduced.[13] Aerospace Corporation has conducted a detailed evaluation of ponding[12] and is currentlyccontinuing programs in the area. Data from this initial study have been updated and cost ranges are $0.2 to $3 per ton of sludge (50 percent solids) for unlined pond disposal and $0.5 to $10 per ton of sludge for lined pond disposal.[8] The large range and higher upper limits reflect uncertainty in regard to unusual local situations. A cost of $3 per ton for sludge disposal in a lined pond was repeated to be typical. Costs would be nearer $1 per ton if disposal in an unlined pond is allowed. Typical truck hauling rates for stabilized fly ash for a distance of 5 miles are reported to be $0.75/ton.[8] This may represent an added cost when offsite ponding or landfill is required. Based on the above data, GCA estimates a typical cost of $4/ton for sludge disposal. Union Carbide reports that the cost of offsite disposal at their activated carbon plant would be $6/ton.

Landfill is also a feasible disposal method although use of this option is currently limited. Dewatering and sludge stabilization or chemical fixation are usually required for landfills. Chemical fixation and landfilling is reported to cost more than ponding in most situations, averaging about twice as much. A specific example of chemical fixation and landfill is the Bruce Mansfield No. 1 unit, an 835 Mw system. Projected costs are reported to be $7/ton of sludge including Dravo chemical fixation, acquisition and development of considerable land, and an 8-mile pipeline operation.[11]

While sludge disposal is an important environmental consideration, disposal methods are available and the annual cost should be relatively small, less than 10 percent of the total annual FGD cost.

SECTION IV

COST OF SO_2 CONTROL

GCA contacted Research-Cottrell to obtain a budgetary cost estimate for a Bahco lime scrubbing system to handle the design conditions previously specified in Table 2. Two absorbers, a 10,000 scfm unit and a 15,000 scfm, operating in parallel were recommended by Research-Cottrell.[14] These are standard unit sizes manufactured by Research-Cottrell, but to achieve the required 97 percent SO_2 efficiency under the specified conditions increased gas-liquid contact will be required. This will be accomplished by additional stages. An efficiency guarantee would be available based on a range of specified inlet conditions.[15]

A gas temperature of 400°F entering the scrubber is required. This could be accomplished by water spray cooling although waste heat recovery may also be an attractive option. GCA estimated the water required for cooling and added the quantity and costs to the scrubber requirements. The cost of spray cooling equipment would not be significant.

Utility, material, and labor requirements for the Bahco scrubbing system and precooler to achieve the design specifications in Table 2 are presented in Table 5. About 50 percent of the water requirement would be used for precooling. Treated process water is not required and plant waste water, such as cooling tower blowdown, may be suitable. Maintenance requirements of 3.5 percent of fixed capital investment for materials and an equivalent cost for labor were based on a TVA study of utility scrubbing systems.[16] Maintenance costs may actually be lower as Research-Cottrell estimated a total of 3 percent of fixed capital

Table 5. UTILITY, MATERIAL, AND LABOR REQUIREMENTS FOR FLUE GAS DESULFURIZATION BASED ON MAXIMUM RATED CAPACITY OF THE CALCINING AND ACTIVATING FURNACES

	BAHCO lime scrubbing (Research-Cottrell)
Utility	
Power kWh/day	4380
Process water 10^3 gal/day	108
Material	
Lime (CaO) ton/day	16.4
Maintenance percent fixed capital investment/year	3.5
Labor	
Operation men/shift	0.50
Maintenance percent of fixed capital investment/year	3.5

investment for materials and labor combined based on operating experience at Cholla. Similarly, GCA used a relatively high estimate for operating labor of 0.5 men/shift based on a Battelle study[13] compared to 0.25 men/shift reported by Research-Cottrell.

The yearly costs for utility, material, and labor are presented in Table 6. These costs are derived from the unit costs in Table 6 and by applying a 73 percent yearly load factor. This yearly average load is based on 11 months of operation per year at an average load of 80 percent. Power and process water unit costs used in Table 6 are the costs reported by Union Carbide. The process water cost is based on using city water. Total utility, material, and labor costs for lime scrubbing would be $394,000 per year.

Capital and annual SO_2 control costs are presented in Table 7. A total capital requirement of $2,288,000 was estimated for a scrubbing system to clean 26,000 scfm of gas, reducing the SO_2 content from 6500 ppm to 200 ppm. The battery limit plant (BLP) cost of $1,600,000 was based on an estimate by the manufacturer.[14] Normal site preparation costs including costs to connect utilities and normal duct work were estimated to be 20 percent of the BLP cost or $320,000. To account for retrofit difficulties including cooling and the stack-furnace configurations an additional retrofit cost of 15 percent of the BLP cost was also applied. A solid waste disposal cost of $6/ton of sludge (50 percent solids) suggested by Union Carbide was used instead of a cost of $4/ton used by GCA for typical facilities.

The average annual cost including operation, cost of capital, depreciation and taxes was $916,000/year equivalent to $0.176/lb sulfur removed or $0.072 per pound of activated carbon produced. This latter cost can be compared to the selling prices for Union Carbide activated carbon, which range from $0.43 to $1.65 per pound.

Table 6. UTILITY, MATERIAL, AND LABOR COSTS FOR THE FLUE GAS DESULFURIZATION AT UNION CARBIDE'S FOSTORIA ACTIVATED CARBON FACILITY,[a] 10^3/YR

	BAHCO lime scrubbing (Research-Cottrell)
Utility	
Power $0.022/kWh[b]	25.9
Process water $0.535/$10^3$ gal[b]	15.5
Total utilities	41.4
Material	
Lime (CaO) $40/ton	176.0
Maintenance	75.6
Total material	251.6
Labor	
Operation $8/man-hour	25.7
Maintenance	75.6
Total labor	101.3
Total utility, material, labor	394.3

[a]Based on 11-month operation at an average load of 80 percent which is equivalent to a yearly load factor of 73 percent.

[b]Union Carbide provided these prices as applicable to this plant.

Table 7. CAPITAL AND ANNUAL SO_2 CONTROL COSTS AT UNION CARBIDE'S FOSTORIA ACTIVATED CARBON FACILITY, 10^3, JUNE 1976

	BAHCO lime scrubbing (Research-Cottrell)
Capital requirement	
Battery limits plant installed[a] (BLP)	1,600
Site preparation and utilities,[b] 20% of (BLP)	320
Additional retrofit requirements, 15% of BLP	240
Fixed capital requirement	2,160
Working capital,[c] 20% of gross operating cost	128
Total capital requirement	2,288
Annual operating cost	
Labor[d]	101.3
Administrative and general overhead,[c] 60% of labor	60.8
Utilities[d]	41.4
Materials[d]	251.6
Local taxes and insurance,[c] 2.7% of fixed capital requirement	58.3
Solid waste disposal, $6/ton[e]	128.0
Gross operating cost	641.4
Total annual operating cost	641.4
Annualized cost	
Annualized capital cost[f]	233.0
Federal income tax[c,g]	41.8
Total annual operating cost	641.4
Average annual cost	916.2
Average annual control cost $/lb S removed	0.176
Average annual control cost $/lb activated carbon produced	0.072

[a] Manufacturer estimate (June 1976).

[b] Normal site preparation: cost to bring utilities to the battery limit plant and connect unit outlet ducts to battery limit plant based on GCA review of similar costs reported in the literature.

[c] Based on utility financing method as modified by the Panhandle Eastern Pipeline Company and described in Reference 13.

[d] See Tables 6 and 7.

[e] Union Carbide provided this unit cost as applicable to the Fostoria Plant.

[f] Total capital requirement is amortized over 20 years at a discount cash flow rate of 8 percent. This works out to an effective rate of 10.185 percent of the total capital requirement per year.

[g] Average federal income tax = 1.731 percent of the sum of the total capital requirement and working capital.

SECTION V

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